Modeling of Visual Perception of a Perspective Scene in an Active Control Task

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How do we use visual information to accomplish aircraft (or vehicular) control?

What features are most important to retain in a simulated visual scene?

Outline

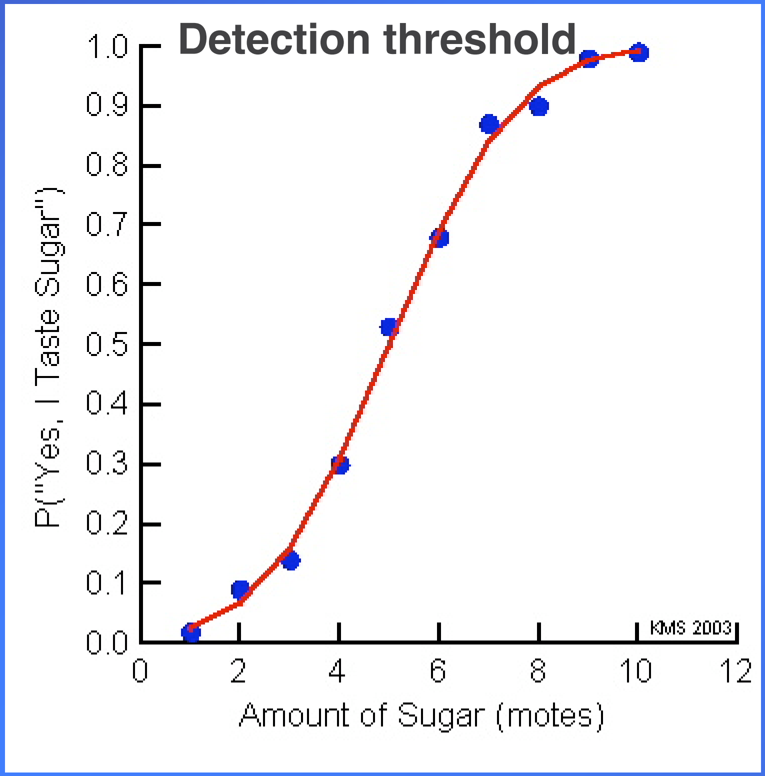
- Background
- Model Description
- Longitudinal Control
- Pitch Control
- Conclusions

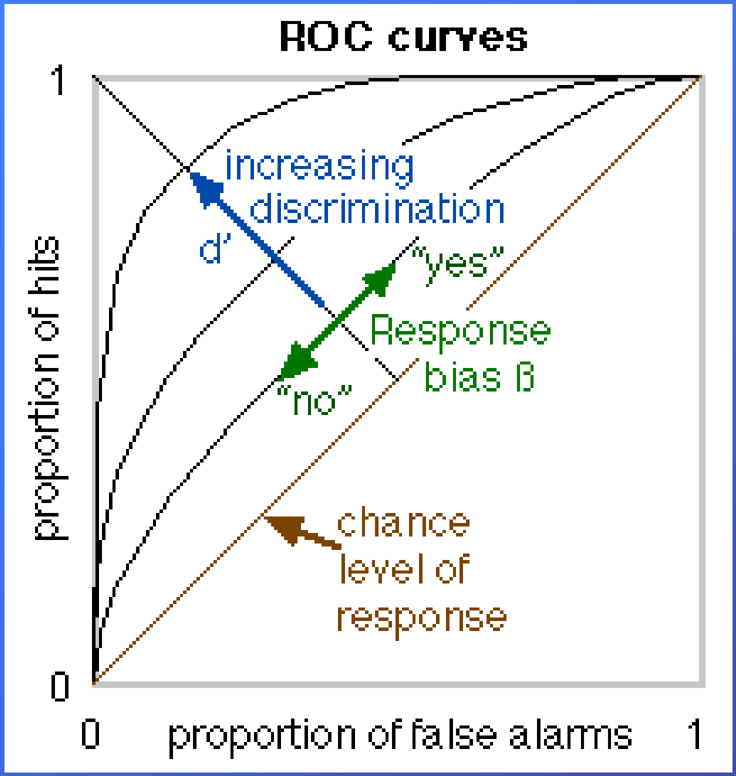
Background

- Traditional Approaches
  - Psychophysics → "Action Happens"
  - Manual Control → "Perception Happens"
- Current Approach
  - Combine traditional Psychophysics methods with Manual Control modeling
- Potential Applications
  - Design: Simulator visual scene, UAV display, cockpit FOV/layout, airport/heliport markings
  - Analysis: Accident investigation

Traditional Psychophysics

- Describes the mappings between physical stimulation and sensation/perception





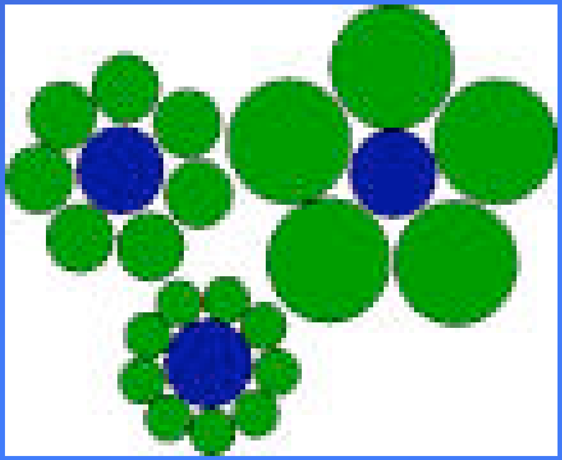
Limits of Traditional Approach

- Data derived from perceptual judgments (verbal), not visuomotor control
- Judgments based on single stimulus cue (e.g., binocular disparity, relative size)

Perceptual Judgments vs. Visuomotor Control

"The visual mechanisms underlying perception and visuomotor control can operate independently…"

- Milner and Goodale, 1996



Titchener circles illusion:
"Eye is fooled, Hand is not"

Solution: "Active Psychophysics" – emerging discipline that our work builds upon

Single Stimulus versus Multiple Cues (Example: Distance)

- Taxonomies of depth cues long developed
  - Bishop Berkeley (18th century)
    - Primary (Physiological)
    - Secondary (Pictorial)
    - Motion (developed later)
- Cue Integration models fairly recent
    - Bruno & Cutting, 1988
    - Massaro & Cohen, 1993
    - Landy Maloney, Johnston, & Young, 1995

Limits of Current Integration Models

- Primarily examine static depth perception
  - Static: motion cues seldom included
  - Depth: relative distance, not closure
  - Perception: not control of range / range rate
- Fail to fully characterize integration dynamics
  - Quality of information, sort of; nature of task, no

"Visual Cue Integration Modeling" – emerging discipline that our work builds upon

Manual Control

- Describes compensation human operator provides as part of a control loop
- *Vehicle characteristics affect information requirements for the human operator*

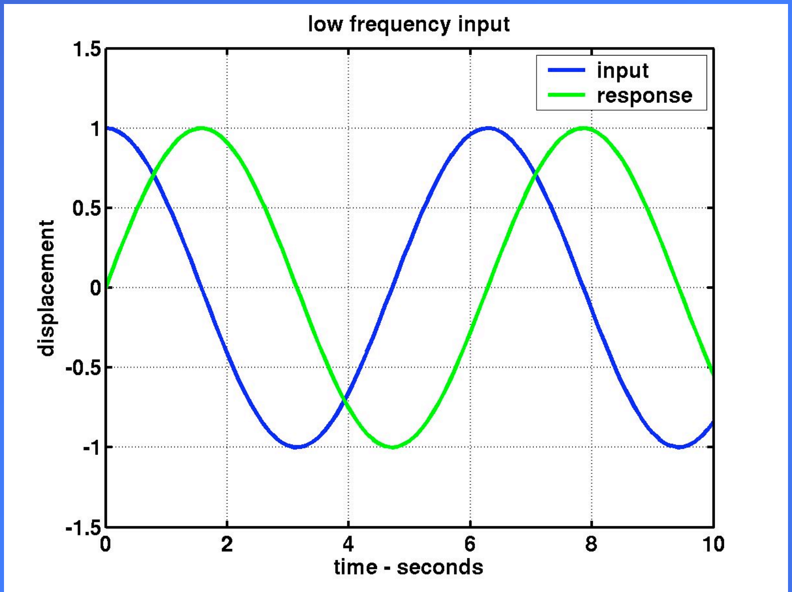
Quick Laplace Tutorial

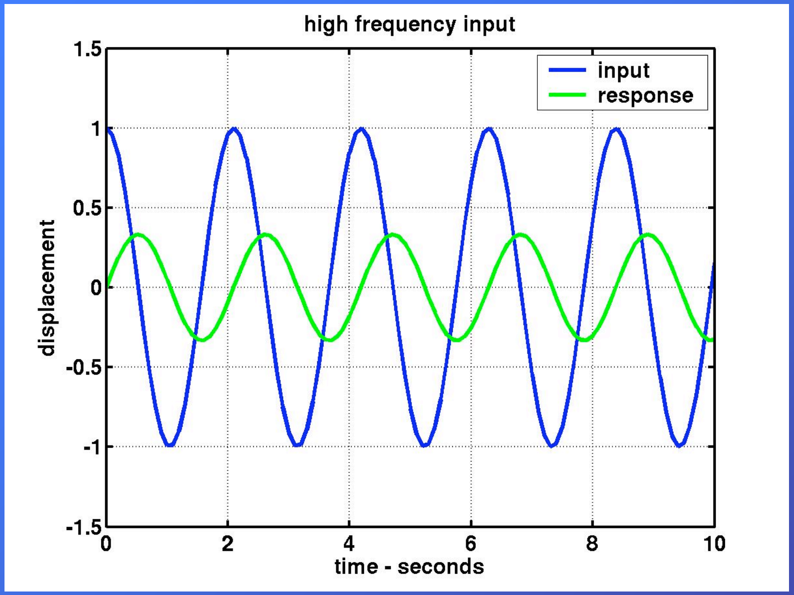
$$\xrightarrow{\text{input } i(s)} \boxed{Y(s)} \xrightarrow{\text{output } o(s)}$$

Description	Laplace	Time
gain	$Y(s) = K$	$o(t) = K\, i(t)$
differentiation	$Y(s) = s$	$o(t) = di(t)/dt$
time delay	$Y(s) = e^{-s\tau}$	$o(t) = i(t-\tau)$
integration	$Y(s) = 1/s$	$o(t) = \int i(t)dt$

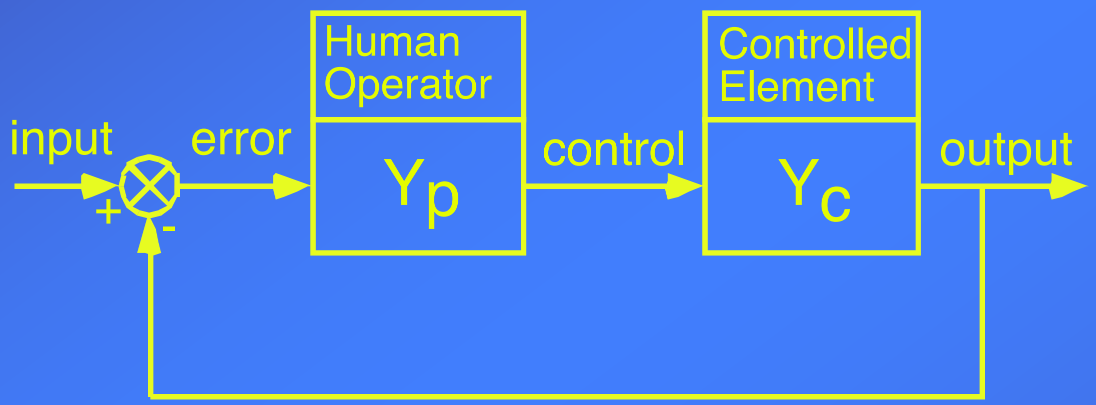
Quick Laplace Tutorial (cont)

An integrator *attenuates* the input



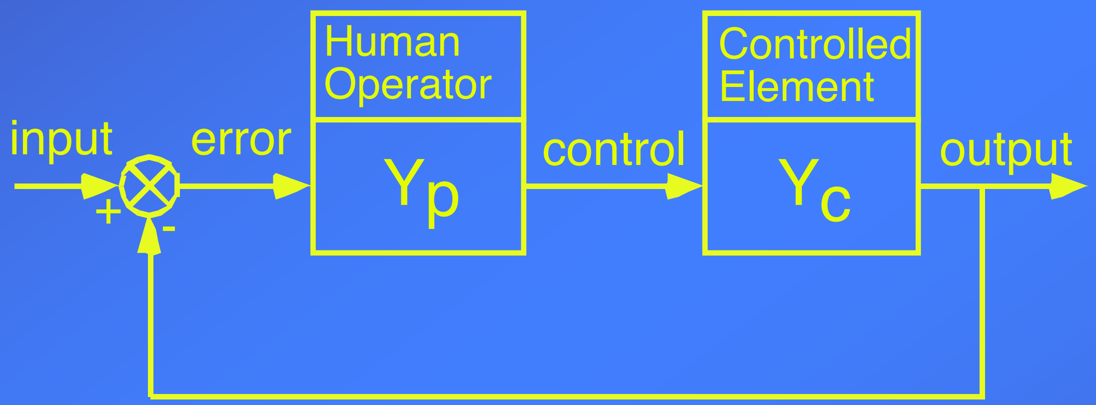


Human Operator Modeling



Operator characteristics vary as a function of the controlled element

Crossover Model



$$Y_p Y_c = \frac{\omega_c e^{-s\tau}}{s}$$

ω_c = gain

$e^{-s\tau}$ = time delay

$1/s$ = integrator

The pilot will provide whatever compensation is necessary to yield an open-loop pilot/vehicle transfer function that resembles K/s in the region of the open-loop crossover frequency.

Pilot Compensation Requirements

$$Y_p Y_c = \frac{\omega_c e^{-s\tau}}{s}$$

$Y_c = K$	$Y_p = K_p\, e^{-s\tau}/s$
$Y_c = K/s$	$Y_p = K_p\, e^{-s\tau}$
$Y_c = K/s^2$	$Y_p = K_p\, s\, e^{-s\tau}$

Manual Control (cont)

Description	Example
Position Control $Y_c = K$	Mouse; tire angle to steering wheel deflection
Velocity Control $Y_c = K/s$	Aircraft attitude w/ SAS; vehicle heading to steering wheel deflection
Acceleration Control: $Y_c = K/s^2$	Spacecraft attitude/position control; vehicle lateral position to steering wheel deflection

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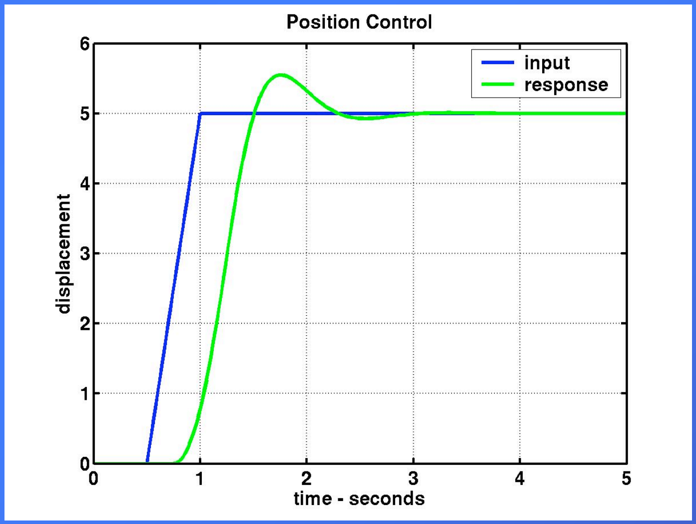

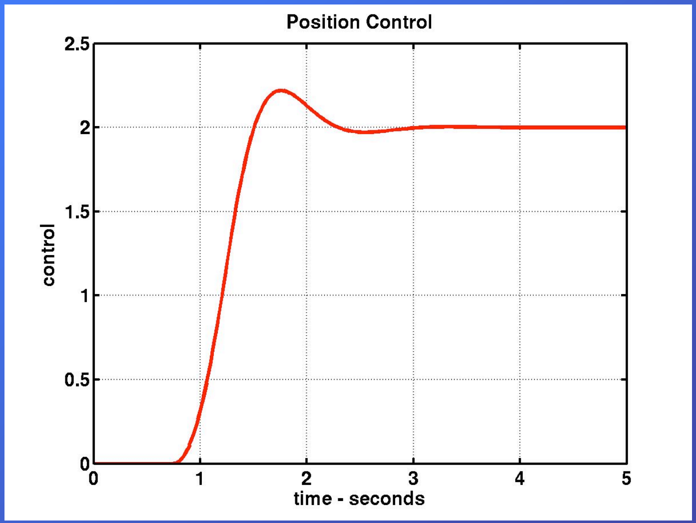

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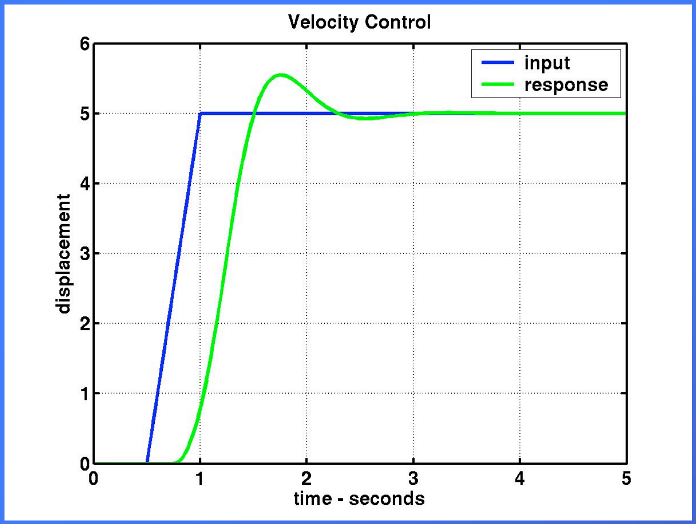

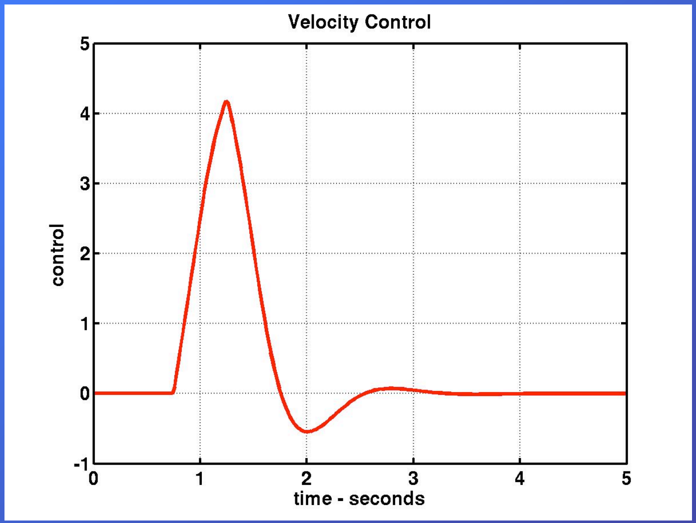

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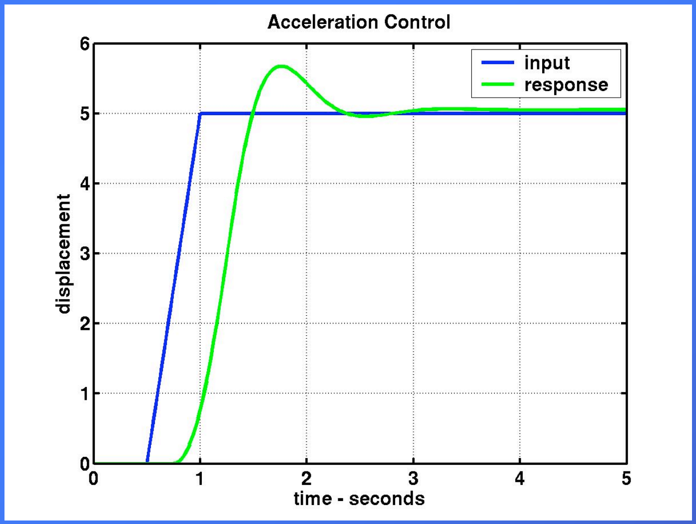
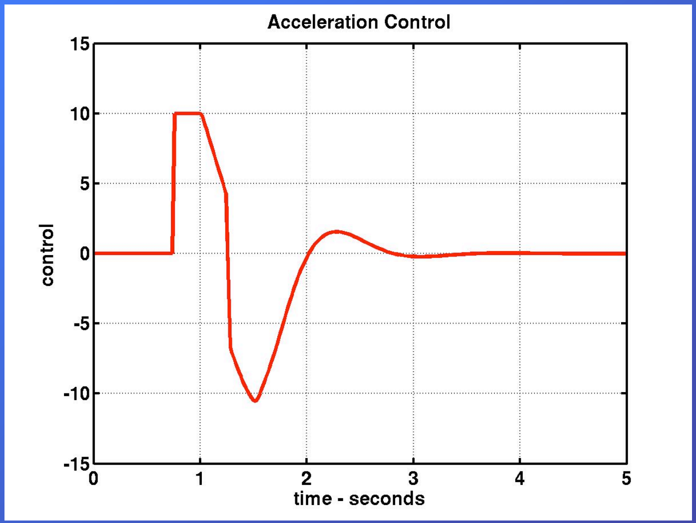
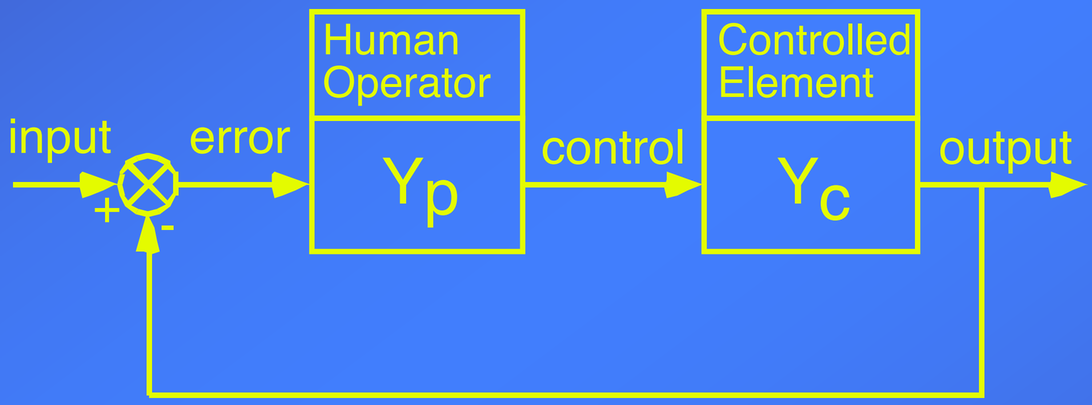




Modeling Approach



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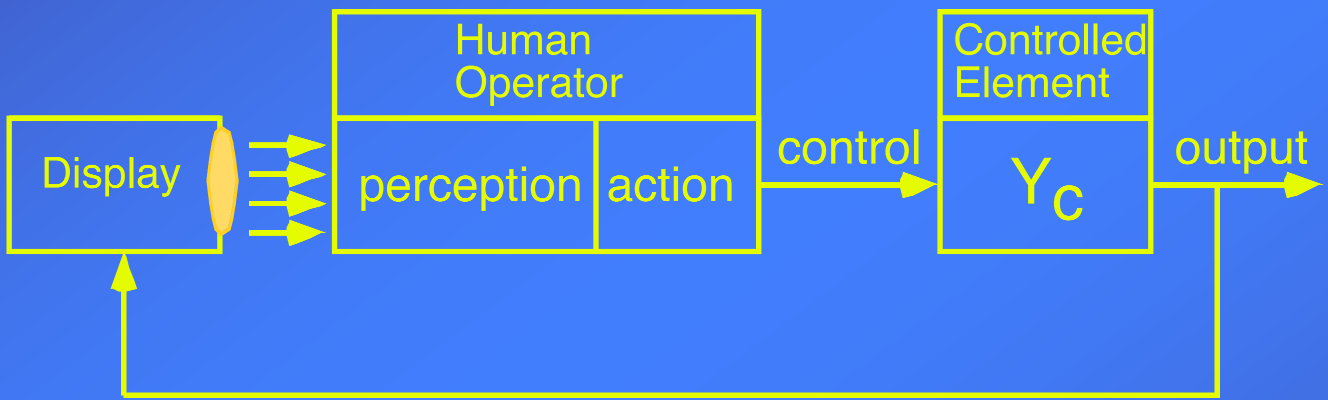
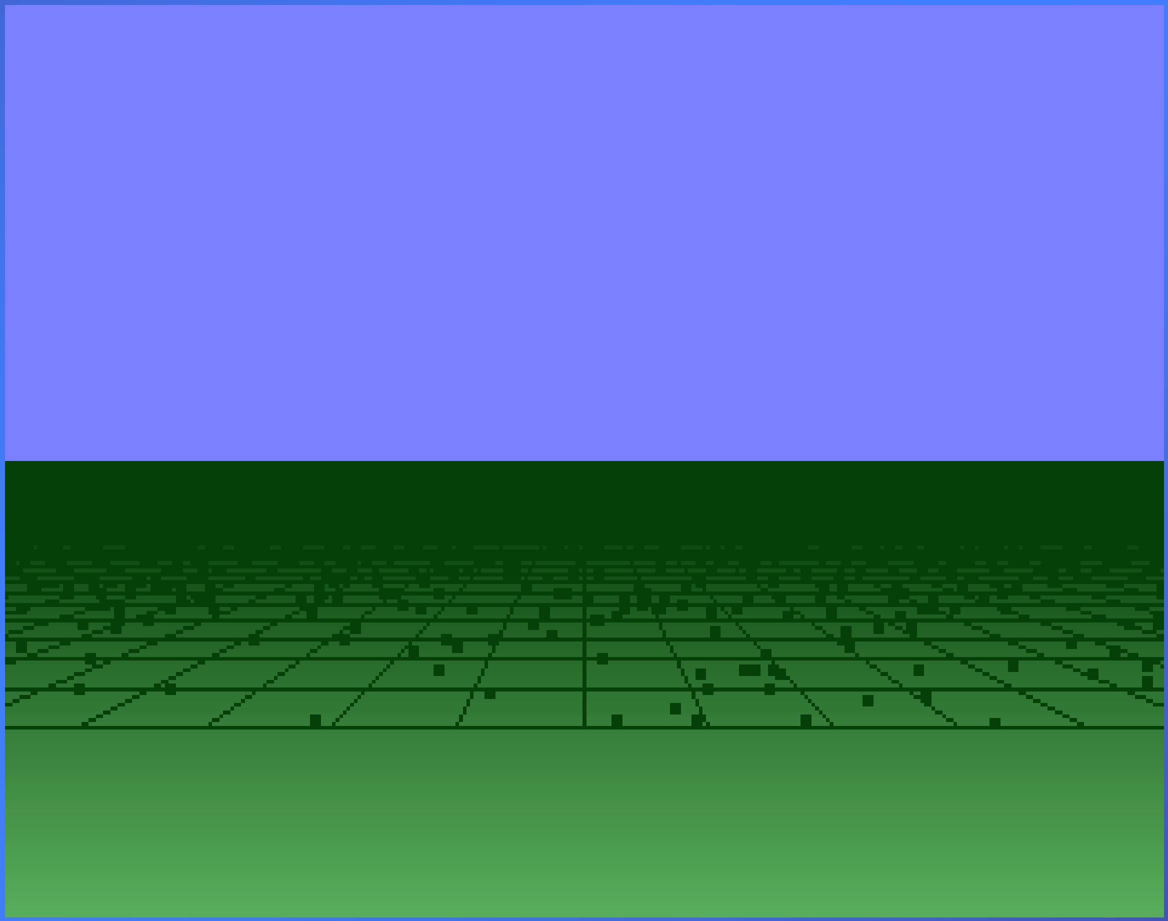


- Represent perception as a combination of vehicle states
- Combinatory weights are a function of visual cues
- Resulting open-loop model should still be consistent with Manual Control characteristics

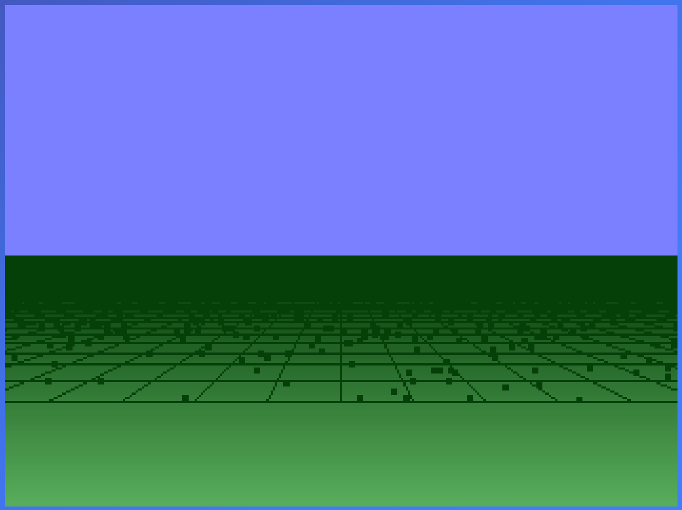
Longitudinal Position Control Task

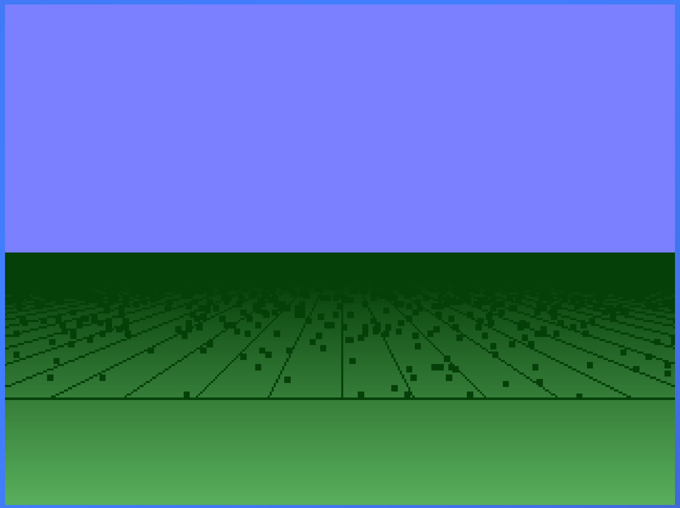
- Objective: determine visual scene characteristics used for position control
  - Displays: varied ground plane markings (lines, grids, dot textures)
  - Disturbances: longitudinal vs longitudinal + pitch
  - Task: maintain longitudinal position (no control of pitch) with lightly-damped acceleration-control task

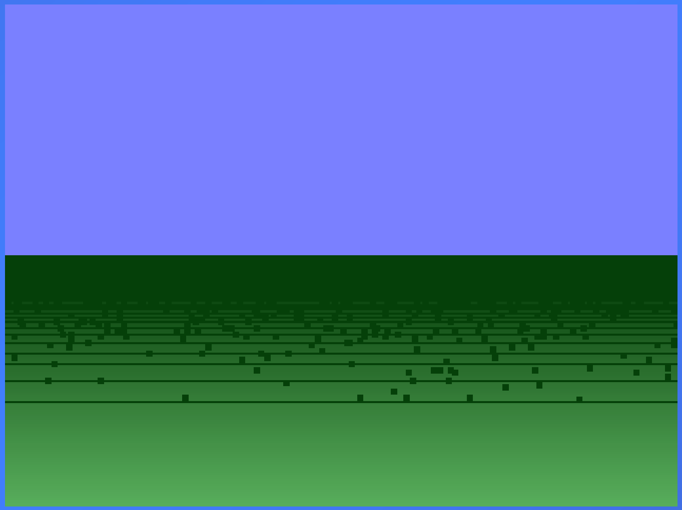
Example Scene

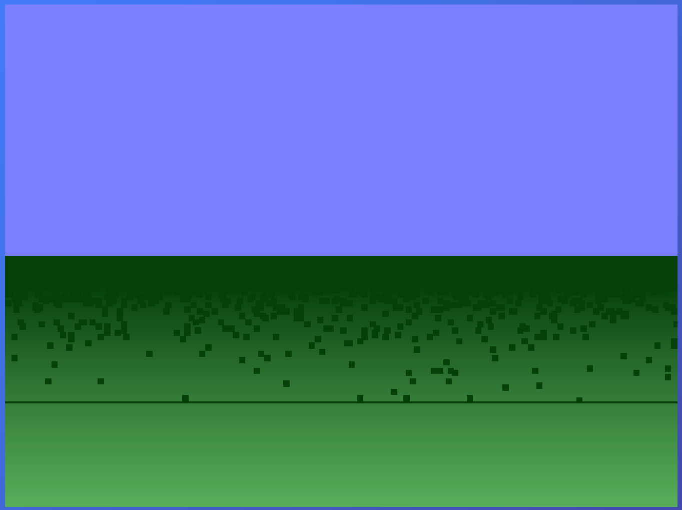


Scene Combinations









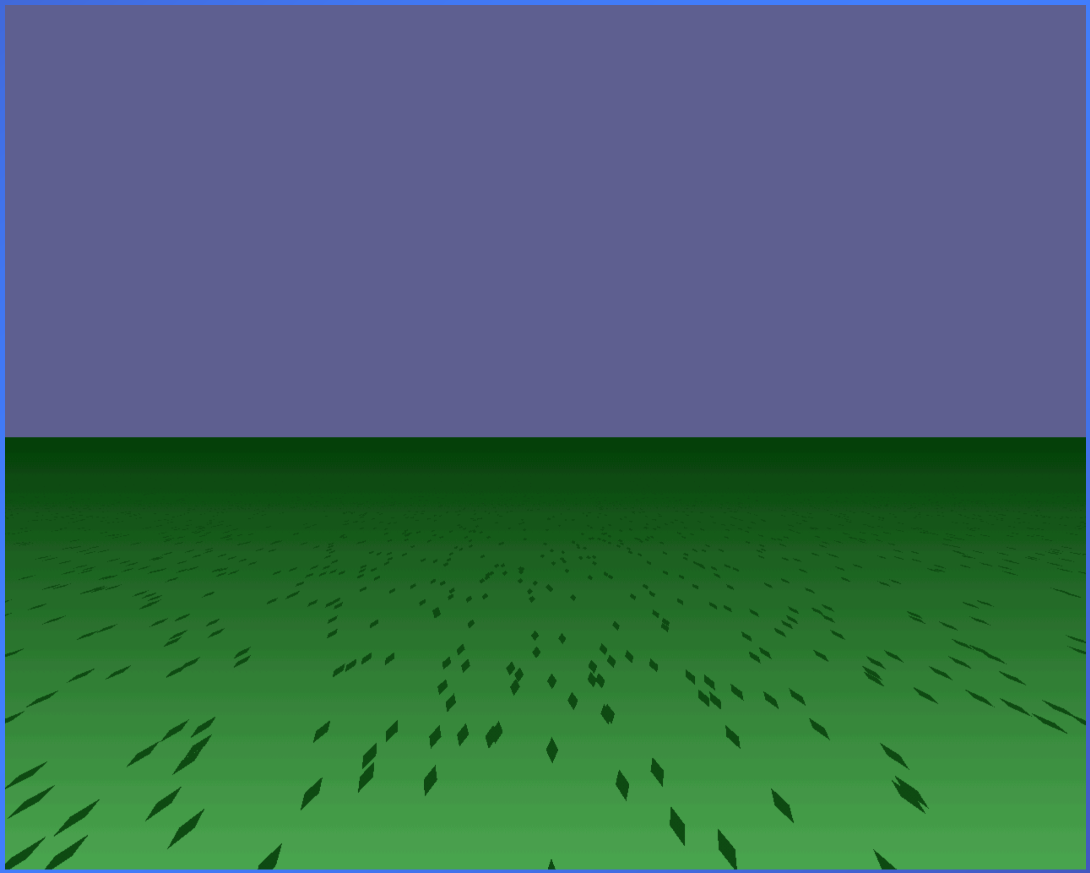
Results

- Identified model accounting for scene perception
- Strong evidence of different cues for position and velocity
- Position perception -> contaminated by pitch
- Velocity perception -> pitch contamination a function of ground markings
  - Lines of splay improve performance
  - Dots improve performance, not as much as lines of splay
  - Operators appear to use lower/outer corners of display for velocity perception

Pitch Attitude Control Task

- Inverse of longitudinal position control: control pitch attitude in the presence of an uncontrollable longitudinal disturbance
- With and without visible horizon (fog)
- Rate-control vs acceleration-control

Example Scene (no fog)



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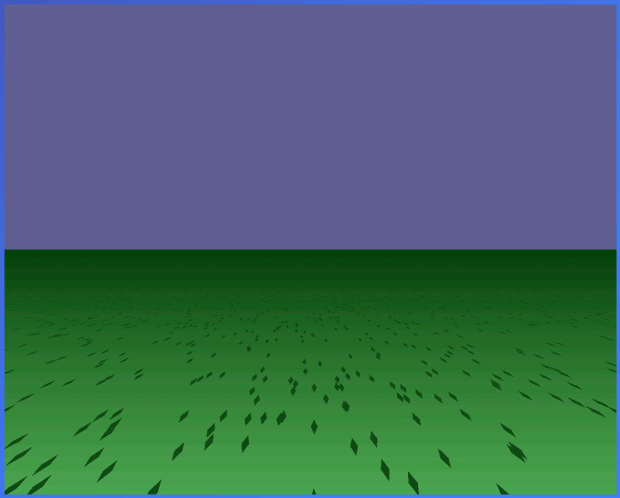

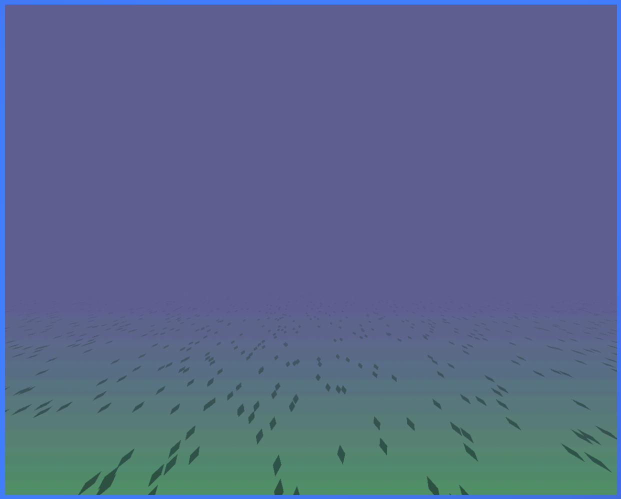

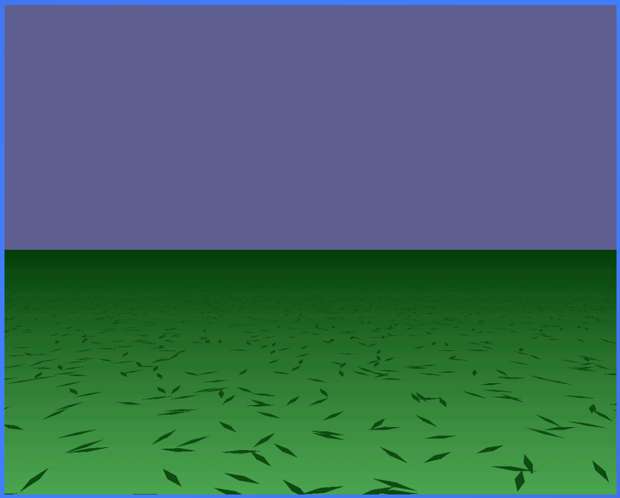

Results

- The horizon is a great pitch attitude cue!
- Ground texture improves velocity sensing and performance in the acceleration control task
- "Aligned" texture (providing splay cue) improves performance in the acceleration control task

Conclusions

- Important to consider task and vehicle dynamics when designing simulated visual scenes
- Scene texture, particularly in the near field, supports motion detection
- Conversely, care must be taken to prevent temporal aliasing artifacts
- Larger field-of-views help to support improved distinction between positional and attitudinal state changes

Future Plans

- Extend modeling techniques to more complex/coupled vehicle dynamics
- Extend modeling techniques to more complex scenery
- Examine visual motion detection and methods to minimize objectionable motion-related simulator artifacts